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EPA's LIMB (Environmental Protection Agency's Limestone Injection with Multistage Burners) Technology Development Program

(U.S.) Environmental Protection Agency
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16. ABSTRACT The paper gives an overview of EPA's Limestone Injection with Multistage Burners (LIMB) program, a program for research, development, and demonstration of cost-effective emissions control technology for coal-fired boilers that can reduce both sulfur oxides (SOx) and nitrogen oxides (NOx). The LIMB concept uses low-NOx burners plus sorbent injection to control these pollutants simultaneously. LIMB technology represents a lower cost alternative to currently available SOx control approaches such as flue gas desulfurization, coal cleaning, and coal switching. LIMB technology is especially attractive where coal-fired boilers must be retrofitted to minimize emissions of NOx and SOx, which are major acid rain precursors. This is due to LIMB's relative ease of retrofit to both small and large coal-fired boilers and its lower cost. LIMB performance goals are: (for retrofit) to achieve a 50-60% reduction of both SOx and NOx from uncontrolled levels; and (for new units) to achieve a 70-80% reduction of NOx and a 70-90% reduction of SOx from uncontrolled levels.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field Group
Pollution	Pollution Control	13B
Nitrogen Oxides	Stationary Sources	13A
Boilers	LIMB Program	08G
Limestone	Low-NOx Burners	21D
Coal	Sorbent Injection	21B
Combustion		07B
Sulfur Oxides		

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New Processes

EPA's LIMB Technology Development Program

This technology represents a lower cost alternative to currently available SO_x control approaches such as flue gas desulfurization, coal cleaning, and coal switching.

David G. Lachapelle, U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711

Limestone Injection with Multistage Burners (LIMB) is EPA's program for research, development and demonstration of cost-effective emissions control technology for coal-fired boilers that can reduce both sulfur oxides (SO_x) and nitrogen oxides (NO_x). The LIMB concept uses low-NO_x burners plus sorbent injection to simultaneously control these pollutants. It represents a lower cost alternative to currently available SO_x control approaches such as flue gas desulfurization, coal cleaning, and coal switching.

This technology is especially attractive where coal-fired boilers must be retrofitted to minimize emissions of NO_x and SO_x, which are major acid rain precursors. It is relatively easy to retrofit to both small and large coal-fired boilers, and can cost less. LIMB performance goals are:

- *For retrofit*, to achieve a 50 to 60% reduction of both SO_x NO_x from uncontrolled levels.
- *For new units*, to achieve a 70 to 80% reduction of NO_x and 70 to 90% reduction of SO_x from uncontrolled levels.
- *For both retrofit and new units*, to achieve these performance goals at total plant investment costs of at least $100/kW less than the major technology alternative, flue gas desulfurization.

The current program is structured to address the major technology areas requiring optimization to support an initial demonstration on a pulverized-coal wall-fired utility boiler. Major focus is on:

1. Basic research, and bench- and pilot-scale development in support of LIMB.
2. Prototype testing.
3. Process analysis and wall-fired demonstration.

Currently, emphasis is being placed on increasing the applicability of retrofits to an existing boiler population that does not have NO_x and SO_x controls. The program is also focusing on new boilers where increased design flexibility could give the potential for higher NO_x and SO_x control levels.

Basic research, and bench- and pilot-scale development

In-house and extramural activities will provide the basic understanding of the controlling phenomena essential for success. These activities will develop information on the fundamentals of sorbent reaction chemistry, establish scale-up parameters for LIMB, and support the LIMB demonstration. Three major goals of this program area are:

- To develop methods for generation and/or injection of high surface area superactive sorbents that have the potential for highly efficient SO_x capture and improved LIMB cost effectiveness.
- To provide an understanding of the effects of interactions between sorbent and coal mineral matter and activity promotors such as Na_2CO_3. These interactions are of paramount importance because they affect sorbent performance and boiler operation from slagging, fouling, and particulate collection standpoints.
- To evaluate the feasibility of further reducing LIMB operating costs through recycle of partially spent sorbent and/or reuse of the sorbent/ash mixture.

Prototype testing

This extramural program is structured to provide the industry with performance evaluation of low-NO_x burners with sorbent injection. These detailed evaluations will further increase industry's confidence in LIMB technology and will establish the technically achievable SO_x/NO_x levels for use by decision makers. Further, activities in these areas will provide the initial burner and sorbent injection system design required for its demonstration. Three major goals of this program area are:

- To provide scale-up criteria for use of conventional and superactive sorbents in a large [100×10^6 Btu/h (29 MW)] experimental facility that simulates the flow patterns and thermal gradients of typical wall-fired furnaces.
- To extend scale-up criteria for sorbent injector configurations, locations, etc., to support a planned demonstration of this technology on a tangentially coal-fired utility boiler. This systematic study will utilize cold flow modeling plus combustion tests on a large experimental facility [25 to 100 $\times 10^6$ Btu/h (7 to 29 MW)] that simulates the unique flow pattens of this furnace.
- To provide support to a cooperative program for evaluating LIMB on a small (20 to 40 MWe) boiler. This effort augments the work performed in experimental facilities because it considers critical boiler-related conditions such as

Figure 1. Integrated LIMB system.

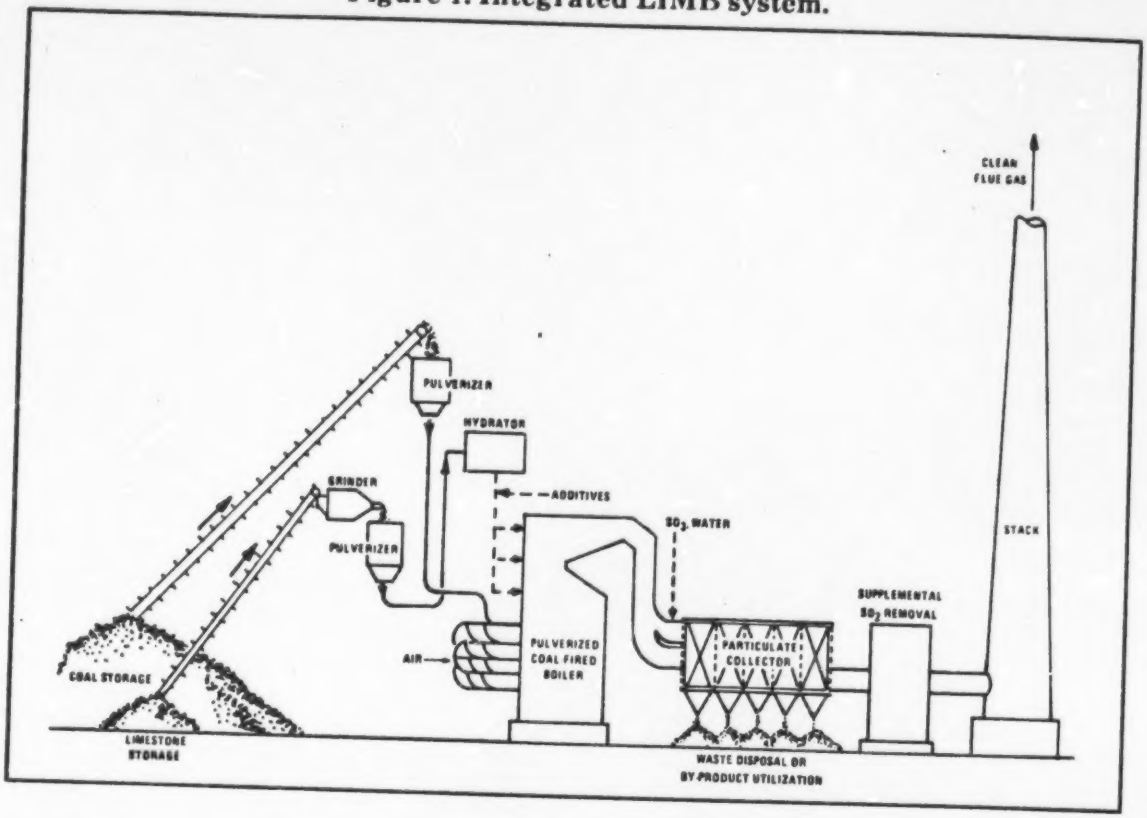
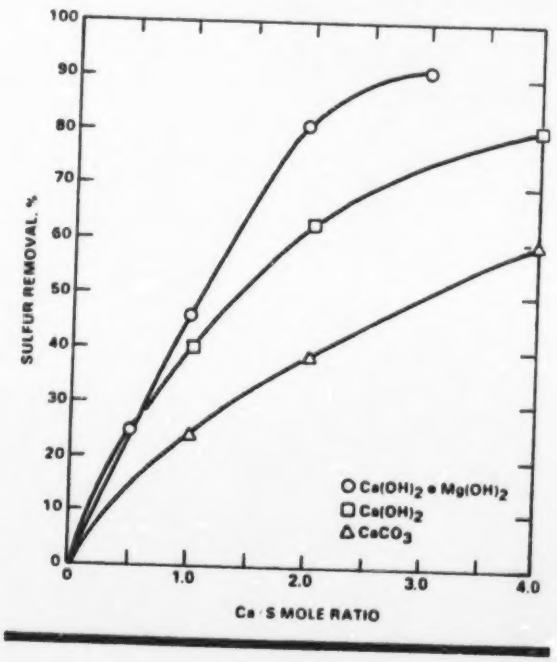


Figure 2. Typical sorbent performance.



slagging and fouling, convective pass residence time and tube spacing, air heater and particulate control system performance, and ash disposal systems.

Process analysis and wall-fired boiler demonstration

This extramural program provides design and engineering criteria for applying LIMB technology to existing wall- and tangentially-fired utility boilers. It provides the basis for cost/benefit analyses and extends the applicability of the technology. It supports the planned demonstration projects. Four major goals of this program area are:

- To synthesize and generalize the critical design, engineering, and economic criteria into an integrated form available for ensuring its maximum success and widest applicability.
- To demonstrate that a 50 to 60% reduction of both SO_x and NO_x can be achieved by retrofitting LIMB technology on a wall-fired utility boiler.
- To demonstrate that a 50 to 60% reduction of both SO_x and NO_x can be achieved by retrofitting LIMB technology on a tangentially-fired utility boiler.
- To provide and support efficient and timely transfer of the latest research, development, and demonstration information to Congress, industrial users, and the engineering and research communities.

Why LIMB program?

The use of sorbents to control emissions of SO_x from coal-fired power plants is not a new concept. It was evaluated most extensively during the period 1968 to 1971. Results from these early demonstration studies showed poor SO_2 removal efficiencies, typically in the range of 10 to 40% using limestone and dolomite. These unfavorable results prompted abandonment of dry sorbent injection as an SO_2 control technique. Flue gas desulfurization utlimately became the SO_2 control method of choice. Recently, the potential of the sorbent injection process has been reexamined principally because of: 1) a need to develop low-cost SO_2 control technology for acid rain control strategies; 2) pilot-scale tests indicating that significantly higher SO_2 capture could be achieved at reasonable alkali to sulfur ratios; and 3) an improved understanding ot the critical process variables that affect sorbent performance.

Table 1. LIMB program research considerations.

Sorbent	Fuel	Boiler
Type	Low to high sulfur	Type (wall and tangentially fired)
Chemistry	Subbituminous to bituminous	Injection methods and locations
Activation	Ash interactions	Time/temperature requirements
Surface activity		Heat transfer
Particle size		Slagging/fouling
Promotors		Operability
Sulfation		Waste disposal
Deactivation		Scale-up and generalization
Regeneration		Economics

In late 1980, EPA's LIMB program was initiated with a goal of demonstrating the process in 1987. Since its initiation, the program has systematically focused on the critical process parameters that require resolution to ensure a successful demonstration. These encompass the full range of sorbent/fuel/boiler related considerations, Table 1. These and other parameters are being systematically evaluated in EPA's program.

The chemistry of sorbent injection is globally straightforward. A sorbent (e.g., limestone) is flash-calcined to lime and subsequently reacts with SO_2 in the presence of O_2 to form $CaSO_4$. The overall reaction is represented as:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

$$CaO + SO_2 + \tfrac{1}{2} O_2 \rightarrow CaSO_4$$

The sulfation window (i.e., the temperature regime where the sulfate is formed) is currently felt to be between 2,250 and 1,650°F (1,232 and 899°C). This suggests that the sorbent might be injected somewhere just above the furnace outlet plane and ahead of the pendant superheaters. Supplemental SO_2 removal to achieve New Source Performance Standards control levels (up to 90%) could be obtained using a spray dryer module following the LIMB system, Figure 1.

Sorbent peformance

The LIMB program is evaluating a wide range of potential sorbents. Pilot-scale data for three different sorbents, Figure 2, were obtained on a 1×10^6 Btu/h (293 kW) experimental combustion facility firing an Indiana coal with 2.3% sulfur. The performance results for limestome, calcium hydroxide, and pressure-hydrated dolomitic lime correspond quite well with the specific surface area of these sorbents as:

$CaCO_3$: 5 to 15 m^2/g

$Ca(OH)_2$: 20 to 30 m^2/g

$Ca(OH)_2 \cdot Mg(OH)_2$: 35 to 45 m^2/g

The thermal environment and residence time of the sorbent in the sulfation window for these test results is representative

Table 2. Major economic premises for capital cost.

	New Units	Retrofit Units
Base year	1985	1985
Book life, years	30	15
Tax life, years	15	5
Inflation rate, %/yr	8.5	8.5
Debt/equity ratio	50/50	50/50
Debt cost, %/yr	11.0	11.0
Preferred stock ratio, %	15	15
Preferred stock cost, %/yr	11.5	11.5
Common stock ratio, %	35	35
Common stock cost, %/yr	15.3	15.3
Weighted cost of capital, %/yr	12.5	12.5
Federal plus state income tax rate, %	50	50
Property taxes and insurance, %/yr	2	2
Investment tax credit, %	10	10
Levelized carrying charge rate, %	15.3	16.01

Table 3. Major economic premises for operating and maintenance costs.

	New Units	Retrofit Units
Base year	1985	1985
Unit capacity factor, %	62.8	62.8
Book life, years	30	15
Tax life, years	15	5
Levelizing factor	2.314	1.714
Waste disposal cost, $/ton	7.66	7.66
Operating manhours/yr		
LIMB	43,800	43,800
FGD	55,460	55,460
Average labor rate, $/h	23.37	23.37
Limestone cost, $/ton[a]	17.88	17.88
Water, $/1,000 gal	0.77	0.77
Process steam, $/1,000 lb	4.84	4.84
In-plant power, mills/kWh	58	58
Coal cost, $/$10^6$ Btu	2.61	2.61

[a] A variety of sorbents can be used with LIMB. Costs for alternate sorbents are indicated in Figures 3 and 4 and in Table 6.

SI Conversion: L = gal × 3.79; kg = lb × 0.454; mm = mil × 0.0254; MJ = kWh × 3.60; kJ = Btu × 1.055.

Table 4. Technology-related assumptions for LIMB.

Process Component	New Units	Retrofit Units
Sorbent injection system	✓	✓
Low-NO_x burner upgrades	a	b
Economizer upgrades	c	d
Sootblower upgrades	✓	✓
Particulate collector type:		
Electrostatic precipitator		e
Baghouse	f	
SO_3 conditioning		e
Dry waste disposal	✓	✓

a. New units are assumed to be already equipped with burners capable of meeting the current NO_x standard of 0.6 lb/10^6 Btu for bituminous coal and 0.5 lb/10^6 Btu for subbituminous coal.

b. Retrofit units are assumed to be backfit with improved burners capable of meeting NO_x emissions of 0.7 lb/10^6 Btu.

c. New units are assumed to be already equipped with a bare tube economizer.

d. Retrofit units are assumed to have an existing finned tube economizer which is replaced with a bare tube economizer.

e. Retrofit units have upgraded ESPs to handle the additional solids loading plus SO_3 conditioning to improve resistivity.

f. New units have baghouses which are not charged off as a LIMB-related cost.

SI Conversion: kg = lb × 0.454; kJ = Btu × 1.055

of what is expected to occur in boilers for which LIMB has applicability. Residence time calculations for typical U.S. boilers indicate that sulfation window residence times of 0.9 to 1.2 s are typically available. With proper mixing of sorbent and flue gases, these times should be adequate to yield the performance levels shown. The improved performance of the higher surface area sorbents has caused us to focus on these as potential candidates for use with LIMB. Experimental programs are continuing to study these in detail and to evaluate the overall economics of these sorbents since they are more expensive than conventional limestone.

Another area that shows promise in terms of improved performance is with the use of promoters. These are mineral substances that can be added in relatively small amounts to the sorbent to enhance its sulfur capture potential. Very preliminary work conducted indicates that the use of a promoter such as sodium carbonate can increase limestone and $Ca(OH)_2$ performance by about 1.4 times that typical of the unpromoted sorbents.

Costs of SO_2 control technologies

LIMB technology offers economic advantages over conventional wet flue gas desulfurization (FGD) methods when moderate SO_2 control levels (45 to 65%) are required. The costs of these SO_2 control technologies have recently been evaluated in considerable detail by EPA based on work conducted by TVA (*1*), Combustion Engineering, Inc. (*2*), PEDCo Environmental, Inc. (*3*), and in-house cost analysis work performed by AEERL.

Since the SO_2 removal efficiencies are different for LIMB and FGD, cost comparisons are presented on a normalized basis; i.e., cost per ton of SO_2 removal. The cost analysis procedures are based to the maximum extent possible on guidelines suggested by the Electric Power Research Institute (*4*). The current dollar analysis method is used with costs expressed in 1985 dollars. For retrofit units 15-year levelized costs are used, whereas 30-year levelized costs are used for new units. Internally consistent costs and/or factors for such items

Table 5. Boiler and coal characteristics selected for LIMB and FGD economic analysis.*

Unit Size, MWe	Status	Net Plant Heat Rate, Btu/kWh	Coal Characteristics HHV, Btu/lb	% S	% Ash
300	Retrofit	9,500	11,700	3.36	15.14
300	Retrofit	9,500	11,700	1.92	15.08
500	New	9,500	11,700	1.92	15.08
500	New	10,500	8,200	0.48	6.3

* Wall-fired boilers are used in these case studies.

SI Conversion: kJ = Btu × 1.055; MJ = kWh × 3.60; kg = lb × 0.454

Table 6. Sorbents and performance data used for LIMB economic analysis.

Sorbent	Sorbent Cost, $/ton	Retrofit Ca/S	Retrofit SO_2 Control, %	New Ca/S	New SO_2 Control, %
Vicron $CaCO_3$	18[a]	2.5	45	—	—
Longview $Ca(OH)_2$	45	2.0	62	2.7	70
Longview $Ca(OH)_2$	45	—	—	4.0	82
Corson $Ca(OH)_2$·$Mg(OH)_2$	60	1.4	62	1.63	70[b]
Corson $Ca(OH)_2$·$Mg(OH)_2$	60	—	—	2.1	82[c]
Promoted $CaCO_3$	25	2.0	56	—	—
Promoted $Ca(OH)_2$	50	1.5	65	1.8	70[b]
Promoted $Ca(OH)_2$	50	—	—	2.8	82[c]

[a] Actual cost used was $17.88/ton.
[b] Minimum percent control required by NSPS for the 0.48% S coal.
[c] Minimum percent control required by NSPS for the 1.92% S coal to be at or below 0.6 lb/10^6 Btu.
SI Conversion: kg = lb × 0.454; kJ = Btu × 1.055

as operating and maintenance labor, maintenance material, administrative and support labor, consumables, and levelization factors have been employed to ensure that the LIMB and FGD costs are on an equivalent basis. Tables 2 and 3 present the major premises used in the economic analysis. In addition to those shown, other indirect charges and assumptions enter into this rather complex analysis; e.g., engineering and home office overhead (including fee), project and process contingencies, cost of general facilities, preproduction costs, inventory capital, and land. Some of these charges are based on a percentage of process capital cost, while others are computed based on specific site requirements, cost and quantities of consumables, allowance for funds during construction, etc. Most charges and assumptions are consistent within and between LIMB and FGD.

Table 4 gives some of the technology-related assumptions used in developing the costs for LIMB. For FGD, the design is assumed to employ spray tower absorbers utilizing forced oxidation with landfill disposal of solid waste. The FGD system employs one spare absorber train for new units and none for retrofits. It includes emergency bypass of 50% of the flue gas normally scrubbed and reheat to 175°F (79°C).

For FGD systems, the stoichiometric ratio is defined as the moles of calcium per mole of SO_2 *absorbed*. For LIMB, the stoichiometric ratio is defined as the moles of calcium per mole of sulfur in the fuel. Typically, a stoichiometric ratio of 1.4 is used with FGD for 90% SO_2 control, whereas for LIMB, stoichiometric ratios of 1.4 to 2.5 might be employed depending on the sorbent and required control level. A LIMB system using a Ca/S ratio of 2 and achieving 50% SO_2 control would be equivalent to a stoichiometric ratio of about 4 using FGD's nomenclature for stoichiometric ratio. The figures in this ar-

Figure 3. Comparison of SO_2 control technology cost: 300 MWe retrofit.

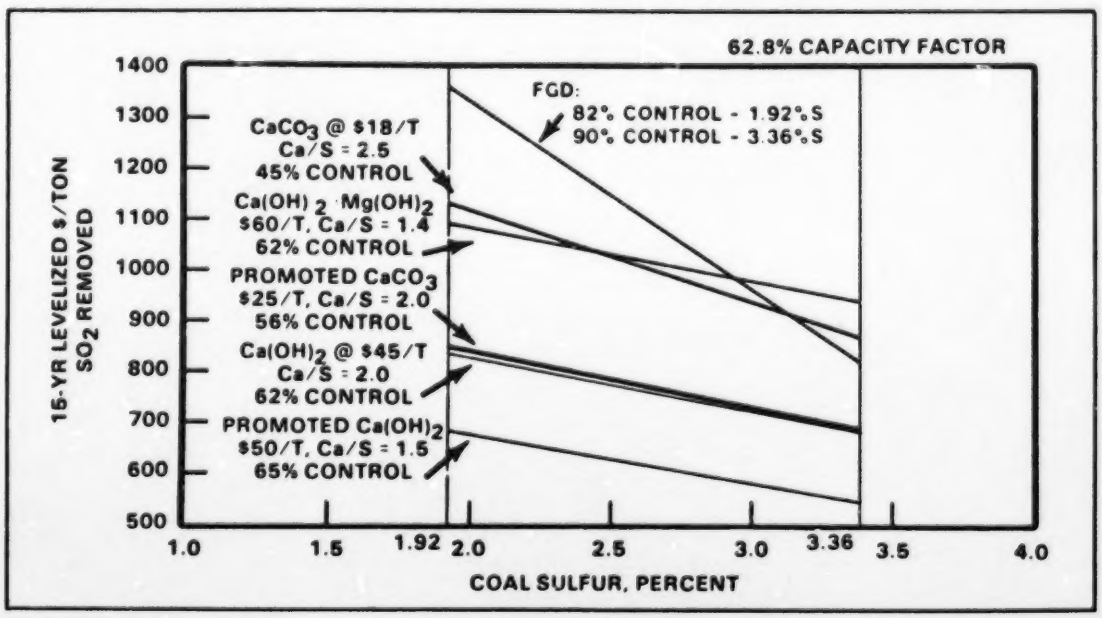


Table 7. Costs for retrofit LIMB and FGD.

Basis: 300 MWe Wall-fired Units at 62.8% Capacity Factor; 1985 Dollars

Technology	Sulfur, %	Sorbent	$/Ton SO_2	Total Capital Requirement, $/kW	15-Year Levelized Revenue Requirement, mills/kWh[a]	15-Year Levelized Capital, mills/kWh	15-Year Levelized Operating and Maintenance, mills/kWh
FGD	1.92	$CaCO_3$	1359	210	17.30	6.10	11.20
LIMB	1.92	$CaCO_3$	1135	88	7.99	2.57	5.42
LIMB	1.92	$Ca(OH)_2$	844	79	.14	2.30	5.84
LIMB	1.92	$Ca(OH)_2$·$Mg(OH)_2$	1101	89	10.61	2.59	8.02
LIMB	1.92	$CaCO_3$	855	74	7.47	2.16	5.31
LIMB	1.92	$Ca(OH)_2$	688	64	6.94	1.87	5.07
FGD	3.36	$CaCO_3$	829	239	20.22	6.97	13.25
LIMB	3.36	$CaCO_3$[b]	874	107	10.81	3.11	7.70
LIMB	3.36	$Ca(OH)_2$[b]	691	107	11.64	3.11	8.53
LIMB	3.36	$Ca(OH)_2$·$Mg(OH)_2$	942	122	15.87	3.55	12.32
LIMB	3.36	$CaCO_3$[b]	695	102	10.63	2.97	7.66
LIMB	3.36	$Ca(OH)_2$[b]	556	87	9.78	2.54	7.24

[a] Includes levelized capital and levelized operating and maintenance charges.
[b] Promoted sorbent.
SI conversion: L = gal × 3.79; kg = lb × 0.454; mm = mil × 0.0254; MJ = kWh × 3.60; kJ = Btu × 1.055

ticle that illustrate the comparative costs of LIMB and FGD use the stoichiometric ratio nomenclature associated with the respective technology: for LIMB, it is shown as Ca/S; for FGD, as Ca/SO_2.

Table 5 gives the boiler and coal characteristics used for the LIMB and FGD economic analysis. The unit sizes selected represent those typical of retrofit and new applications. Wall-fired designs were used in all cases. The coals encompass the sulfur content range targeted for application of these SO_2 control technologies. The net plant heat rate is used in the analysis to determine the required coal flow and corresponding sulfur and SO_2 mass flow rates.

Table 6 gives the sorbents, Ca/S ratios, and SO_2 control levels used in the LIMB economic analysis. The performance data are derived from Figure 2 and from in-house testing of promoted sorbents. The sorbent costs represent delivered

Figure 4. Comparison of SO_2 control technology cost: 500 MWe NSPS.

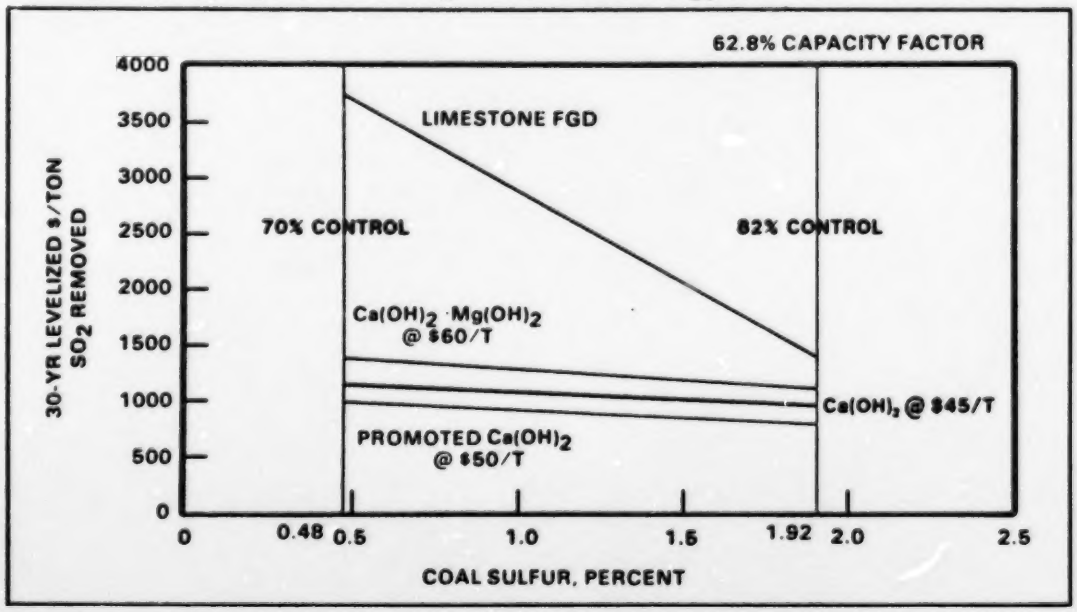


Table 8. Costs for new LIMB and FGD.

Basis: 500 MWe Wall-fired Units at 62.8% Capacity Factor; 1985 Dollars

Technology	Sulfur %	Sorbent	$/Ton SO_2	Total Capital Requirement, $/kW	30-Year Levelized Revenue Requirement, mills/kWh	30-Year Levelized Capital, mills/kWh[a]	30-Year Levelized Operating and Maintenance, mills/kWh
FGD	0.48	$CaCO_3$	3715	158	15.97	4.39	11.58
LIMB	0.48	$Ca(OH)_2$	1134	19	4.87	0.54	4.33
LIMB	0.48	$Ca(OH)_2 \cdot Mg(OH)_2$	1366	21	5.87	0.58	5.29
LIMB	0.48	$Ca(OH)_2$[b]	961	18	4.13	0.49	3.64
FGD	1.92	$CaCO_3$	1377	170	17.53	4.73	12.80
LIMB	1.92	$Ca(OH)_2$	921	27	11.77	0.74	11.03
LIMB	1.92	$Ca(OH) \cdot Mg(OH)_2$	1078	28	13.74	0.79	12.95
LIMB	1.92	$Ca(OH)_2$	761	30	9.69	0.82	8.87

[a] Includes levelized capital plus levelized operating maintenance charges.
[b] Promoted sorbent.
SI Conversion: L = gal × 3.79; kg = lb × 0.454; mm = mil × 0.0254; MJ = kWh × 3.60; kJ = Btu × 1.055

costs to the power plant based on current estimates from sorbent suppliers. The selection of these specific Ca/S ratios and corresponding SO_2 control levels resulted from an initial sensitivity and optimization study, in which a range of Ca/S ratios and SO_2 control levels were evaluated. The values selected represent the optimum economic levels for these sorbents.

For retrofit units, the Ca/S ratio set the SO_2 control level. For new units, required SO_2 control levels to meet New Source Performance Standards were determined for the coals being used, which in turn set the Ca/S ratios.

For intermediate sulfur levels of 1.92%, LIMB is consistently more cost-effective than FGD in the categories of cost per ton of SO_2 removed, total capital requirements, and levelized revenue requirements. Figure 3 and Table 7. For higher sulfur levels of 3.36%, FGD has a slight edge in terms of cost per ton of SO_2 removed over LIMB when limestone and/or pressure hydrated dolomitic lime is used as the LIMB sorbent. This is due in part to the scenario chosen for FGD in that FGD would be retrofit to meet NSPS requirements. For FGD, the differential cost in capital requirement and levelized revenue requirement that occurs in going from 1.92 to 3.36% sulfur is offset to an extent by the increased SO_2 control. For LIMB cases, a constant percentage control is assumed for these coals; consequently, on a cost per ton of SO_2 removed basis, LIMB's cost advantage relative to FGD diminishes for limestone or pressure-hydrated dolomitic lime. However, LIMB continues to exhibit an economic advantage when $Ca(OH)_2$, promoted $Ca(OH)_2$, or promoted $CaCO_3$ is used as the sorbent. Note also that LIMB consistently shows an advantage over FGD in terms of total capital requirement and is always more than $100/kW cheaper.

Figure 4 and Table 8 present the results of the economic analysis of LIMB and FGD for new units meeting NSPS. Here, LIMB exhibits a significant economic advantage over FGD with the low sulfur coal. With intermediate sulfur levels, LIMB continues to be about 20 to nearly 50% lower in cost per ton of SO_2 removed than FGD. For LIMB, the total capital requirement is consistently at least $100/kW less than FGD, Table 8. For LIMB, the cost per ton of SO_2 removed is significantly affected by sorbent cost as reflected in the line representing the pressure-hydrated dolomitic lime. $Ca(OH)_2$, both unpromoted and promoted, appears to be the sorbent of choice for NSPS applications.

Both processes are O&M-intensive; but, as a *percentage* of the total levelized revenue requirements, FGD is slightly less O&M-intensive, Tables 7 and 8. This results because of FGD's lower sorbent cost and somewhat more favorable sorbent utilization. Despite this, LIMB has overall cost advantages for many applications.

In conclusion

EPA's LIMB program is receiving worldwide attention. Many inquiries have come from domestic boiler manufactures and utility companies as well as foreign governments, especially in the past two years. The acid rain issue is an international problem, and cost-effective solutions are being sought. LIMB technology can provide a means for significantly reducing acid rain precursors at reasonable cost. #

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NOTICE

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